PRIOR RESTRICTION:

Claims 17-20 were withdrawn from further consideration as being drawn to a non-elected method of make a laser. Election was previously made without traverse in Paper No. 10.

Claims 17-20 have now been canceled subject to the possible filing of a divisional application.

CLAIM REJECTIONS- 35 USC §112:

Claims 3, 7, 9-11, 14-16, and 32-40 were rejected under 35 USC §112, second paragraph as being indefinite for failing to particularly point out and distinctly claim the subject matter which Applicant regards as the invention.

Claims 1-43 have been canceled in favor of new claims 44-79 which are believed to better define the invention. The noted defects in claims 3, 7, 9-11, 14-16 and 32-40 have been noted and taken into consideration in the drafting of new claims 44-79.

CLAIM REJECTIONS - 35 USC §102

Claims 1-16 and 21-43 were rejected under 35 USC §102(b) as being anticipated by Corzine et al (5,838,715). The Examiner indicated that Corzine disclosed the following elements: substrate 127, a first mirror 107, an active region 125, a semiconductor mirror 111, an anti-phase layer/dielectric spacer 117, a dielectric mirror 449 and an ohmic contact.

Claims 1-43 as previously pending have been canceled, and therefore the rejection is no longer believed to be applicable.

Claims 44-79 have been substituted and are believed to better define the invention.

BRIEF SUMMARY AND BACKGROUND OF THE INVETION:

Before proceeding with a discussion of the newly entered claims and the cited prior art, a brief discussion of the invention is warranted.

The intention of the invention is to provide a VCSEL which emits light in a single spatial mode, namely the fundamental mode. The present invention uses an optical loss mechanism that preferentially suppresses the higher order spatial modes while passing the

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fundamental mode. This mechanism must therefore induce enough optical loss in the path of the higher order modes to suppress lasing in those modes, while inducing as little optical loss as possible in the path of the fundamental mode to allow lasing in that mode. This is generally referred to as mode selectivity.

In typical VCSELs, the active material produces on the order of 1% gain in the resonant cavity and the optical losses are on the order of 0.5% for all lasing modes. These typical losses are mainly due to the desired emission of laser light out of the cavity and somewhat due to free-carrier absorption, which occurs because parts of the VCSEL must be made conducting with impurity doping to supply the active region with the carriers that combine in the active region to produce the gain. As a result, the mode-selective mechanism must induce significantly less than 0.5% additional loss in the fundamental mode to allow efficient lasing (emission of light) in that mode, while inducing well over 1% loss in the higher order modes, to guarantee suppression of lasing in those modes. Since at any given point in a VCSEL the optical percent loss is the same for all modes, the only way to obtain mode selectivity is to concentrate the losses in places where the higher order modes are much brighter than the fundamental mode and to minimize losses wherever the fundamental is approximately as bright or is brighter than the higher order modes.

All the modes, in a VCSEL, propagate along an optical axis that is perpendicular to the planes of the various VCSEL layers. Let us call it the z-axis. Due to the resonant cavity of the VCSEL, the light in all the modes forms a standing-wave pattern. Along the z-axis their intensities vary identically and square-sinusoidally with peak and null positions proscribed by the layer structure of the VCSEL. However, the intensities vary differently for the different spatial modes as a function of "r" the radial distance from the optical axis. Figure 1 (attached) shows a schematic of a cross-section of the radial variations of the intensities of the fundamental mode, LP01, and the next higher mode, LP11. It is important to note that LP01 is much dimmer than LP11 (and it turns out, all the other modes as well) only at large values of r, in what are called the tails of the distributions, where all the intensities are becoming small.

The present invention introduces mode selective loss only in the tails where the selectivity is high. More specifically, mode selectivity is accomplished by a combination of

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two elements, namely an anti-phase layer extending across the entire extent of the VCSEL construction, and an annular reflector positioned at a predetermined radial distance from the optical axis. In this regard, the reflector can be formed by the ohmic contact formed on top of the anti-phase layer. The anti-phase layer and the reflector cooperate to suppress the higher order modes in the tails of the distributions, where the intensity of the higher order modes is higher than the fundamental mode. Please also refer to Figs. 1a, 1b, and 1c of the present invention. Reflections beneath the annular reflector (ohmic contact) are out of phase with reflections from the underlying semiconductor mirror layers thus providing mode selective optical loss beneath the annular reflector, while also allowing a fundamental mode to propagate along the optical axis, i.e. within the interior of the annular reflector. The fundamental mode is subsequently re-phased by a dielectric re-phase layer formed on top of the anti-phase layer. The anti-phase layer is preferably the uppermost layer of the semiconductor mirror, while the re-phase layer is preferably the lowermost layer of the dielectric mirror. The total thickness of the anti-phase and re-phase layers is preferably an integer multiple of ½ wavelength. Another important aspect of the anti-phase and re-phase layers is that they are formed as pristine planar layers and that no unusual processing is required in the manufacture of the device. The anti-phase layer is a semiconductor mirror layer that is simply deposited in different thickness than the underlying semiconductor mirror layers, while the re-phase layer is deposited in a different thickness than the overlying dielectric mirror layers.

DISCSUSSION OF NEW CLAIMS:

Claims 44, 56, 68 and 69 each recite the combination of an anti-phase layer and an annular reflector to provide for the required mode selectivity as discussed. In particular it is noted that the annular reflector is formed on top of the anti-phase layer. Further dependent claims recite the re-phase layer, which re-phases the fundamental mode within the interior of the reflector, and the dielectric mirror on top of the re-phase layer. Still further dependent claims recite that the anti-phase layer is preferably a semiconductor layer, i.e. an uppermost layer of the semiconductor mirror structure, and that the re-phase layer is preferably a dielectric layer, i.e. the lowermost layer of the dielectric mirror structure.

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DISCUSSION OF CORZINE:

First, it is important to reference the cited structures in Corzine and define why they are not equivalent to those claimed. In particular, the discussion will focus on formation and structure of the optical loss layer in Corzine, and the combination of the anti-phase layer and reflector of the present invention.

The Examiner indicated that Corzine disclosed the following elements: substrate 127, a first mirror 107, an active region 125, a semiconductor mirror 111, an anti-phase layer/dielectric spacer 117, a dielectric mirror 449 and an ohmic contact 131, 331.

The substrate 127, first mirror 107, active region 125 and semiconductor mirror 111 are relatively similar to the equivalent structures disclosed in the present invention. However, all of the structures above the semiconductor mirror 111 in Corzine can be readily distinguished from the present disclosure. For purposes of the present discussion, Applicant will primarily reference Figs. 4A-4D or Corzine. Likewise, Applicant will primarily refer to Fig. 4A of the present disclosure for comparison.

Corzine discloses an optical loss layer (117 Fig. 1) or 417A - 417D in Figs. 4A - 4D. There are several physical differences between the optical loss layer of Corzine and the anti-phase layer of the present invention. First, the surface of the optical loss layer in Corzine is not planar, rather it is formed as either convex or concave. Secondly, the optical loss layer in Corzine is located only within the ohmic contact. It does not extend across the entire surface of the semiconductor mirror as seen in the present invention. Thirdly, the optical loss layer of Corzine is formed from a dielectric material. The anti-phase layer of the present invention is formed from a semiconductor material. In the present invention, the anti-phase layer is part of the semiconductor mirror and the annular reflector is formed on top of the anti-phase layer. In Corzine, the optical loss layer is dielectric, and thus an ohmic contact cannot be formed on top as there would be no conductive path. Finally, the optical loss layer of Corzine functions by itself to create optical loss, while the anti-phase layer and the annular reflector cooperate in the present invention to provide optical loss. These physical differences, and their importance to the present invention, are discussed in greater detail below.

As indicated above, one of the primary physical differences in structure is that the

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reflector (ohmic contact, for instance) in the present invention is formed on the anti-phase layer. In Corzine, the optical loss layer is formed only within the interior of the contact. More specifically, the contact is formed on the semiconductor mirror and the optical loss layer is deposited within the center of the contact. Construction of the contact on top of the anti-phase layer is possible in the present invention because the anti-phase layer is a semiconductor layer. In Corzine, the optical loss layer is a dielectric material (insulator), and thus cannot be deposited beneath the contact.

The primary drawback to the curved surface of the optical loss layer in Corzine is that the curved structure introduces unnecessary optical loss in the fundamental mode. As stated above, it is important to note that the fundamental mode is much dimmer than the higher order modes only at large values of r, in what are called the tails of the distributions, where all the intensities are becoming small. The Corzine structures have progressively increasing optical loss as a function of r. In contrast with the present invention where the anti-phase layer is planar, the curved surface of Corzine introduces at least some level of optical loss across the entire laser aperture, including the central portion where the fundamental mode is passed. The only location where there is no optical loss is exactly on the optical axis. Optical loss increases outwardly as a function of r. Corzine does manage to introduce the highest losses in the tail regions, but there all the intensities are low. In addition, as stated above, Corzine introduce losses, albeit smaller, where intensities are much higher (near the optical axis). The total loss for each mode is an integral over volume, of the product of percent loss and intensity. The net mode selectivity for the Corzine structures is thus significantly lower than for the presently claimed structures, since their loss integrals for the fundamental mode are significantly larger.

We also note the difference in function between the optical loss layer of Corzine and the anti-phase layer in the present invention. As light escapes from the Corzine laser, all of the modes within the defined aperture pass through the optical loss layer. The portions of the modes closest to the optical axis are maintained substantially in phase, and thus pass through. However, the curved surface has some effect on all of the modes. The portions of all the modes passing through the outer edges of the optical loss layer are caused to be out of phase. To the extent that the modes in the outer edges of the window are caused to be out of phase,

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and therefore suppressed, the optical loss layer in Corzine can be defined as an anti-phase layer. However, it is more aptly defined as indicated in the Corzine specification, i.e. an optical loss layer. The curved surface causes a varying degree of optical loss over the entire optical cavity. In contrast, the present invention provides a planar anti-phase layer extending across the entire surface of the semiconductor mirror. All modes of the laser, including the fundamental mode, are equally shifted out of phase by the anti-phase layer. The higher order modes generated beneath the annular reflector are retained within the laser structure and suppressed. Because the fundamental mode can now be entirely out of phase, the present invention must also provide a re-phase layer to re-phase the fundamental mode. There is no re-phase layer disclosed in Corzine.

Another important point to note is that the optical thickness of the anti-phase layer ($n_a d_a$, where n_a is the index and d_a is the physical thickness of the anti-phase layer) **must be precisely tuned to the lasing wavelength, λ_{las}**. The requirement is that $n_a d_a = \lambda_{las}/m$, where m is a number greater than 2. The precise value of m is different for different reflectors, as it depends on the optical properties of the reflectors being anti-phased. Moreover, the attached Figure 3 shows that the strong reflectivity cancellation due to the anti-phase layer occurs over a very narrow wavelength range. So, if its thickness is just slightly wrong, the anti-phase layer will create a strong reflectivity cancellation at some other wavelength, and a much weaker reflectivity loss at the lasing wavelength. Thus slight errors in the anti-phase layer thickness will compromise the mode selectivity of the structure. Similarly, in the Corzine structures, slight errors in the initial thickness of the optical loss layer (for designs in their Figures 4A & 4C) or in the etch depth (for designs in their Figures 4B & 4D), can have the perverse effect of inducing more loss near the optical axis than far from that axis as a function of r, or insufficient loss at all values of r. In either case, the desired mode selectivity would be utterly nonexistent. It is submitted that the best way to produce an anti-phase layer, precisely tuned to the lasing wavelength over an entire wafer, is with a semiconductor layer with pristine flat interfaces, as is done in the embodiments in the present application but not in Corzine. In that way, anti-phase layer thickness variations due to growth rate variations will track with the concomitant thickness variations of the lasing cavity and thus with λ_{las}. The optical loss layer

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in Corzine is formed from a dielectric material deposited in a different process and is etched in yet another process. Neither the deposition rate variations nor the etch rate automatically track with the growth rate variations during the formation of the lasing cavity.

With the addition of a re-phase layer (with an optical thickness $n_r d_r$) to the anti-phase layer, the two mirror portions will again produce the proper reflectivity for lasing as is shown in the attached Figure 2. The thickness of the two layers together must be approximately an integral multiple of half the lasing wavelength, that is, $n_a d_a + n_r d_r \approx \lambda_{las}/2$. Slight and even moderate variations in the sum of the thicknesses of the two layers are tolerable, because the reflectivity of the re-phased hybrid mirror is flat over a wide range of wavelengths, as can be seen in the attached Figure 2. Therefore the re-phase layer in the present application does not need to be as precisely tuned, as the anti-phase layer needs to be, and so the re-phase layer can be a dielectric layer. It is submitted that it is not obvious that a dielectric layer can re-phase a semiconductor layer, because the configuration involves two consecutive index drops.

In some instances, a re-phase layer may not be absolutely required. If the annular reflector and the reflector inside the annulus (from the optical axis up to the annular reflector) are very different, the same anti-phase layer thickness may simultaneously anti-phase the annular reflector and substantially rephase the inner reflector. That would occur if the m in the requirement, $n_a d_a = \lambda_{las}/m$, is closer to 2 than to 4 for the annular reflector. That can be the case for some metallic reflectors. Note that Corzine et al never mention metallic reflectors, so this exception is not relevant to their designs. In another approach, the deposited dielectric mirror can serve as both the annular reflector and the inner reflector. In that case, prior to the deposition of the dielectric mirror, a step function mesa must be etched in the re-phase layer. Then, the portion of the dielectric mirror deposited on the flat pristine surface of the mesa is re-phased and passes all but the tails of the modes, and the portion of the dielectric mirror deposited on the exposed annular region of the essentially untouched anti-phase layer essentially passes none of the tails. This produces the necessary mode selectivity, if $n_a d_a = \lambda_{las}/4$ and $n_r d_r \approx \lambda_{las}/4$. To guarantee that the anti-phase layer surface is in fact untouched and the re-phase layer is completely removed outside of the mesa, the etch must be highly selective. That means that the anti-phase layer and the re-phase layer must be two

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significantly different materials. Thus even for this approach, which may appear the most similar to that of Corzine et al, one of the best combinations is a semiconductor anti-phase layer and a dielectric re-phase layer. However, in Corzine et al this important condition is omitted, as their entire loss layer and all of its surfaces are in the same material, while this application specifically emphasizes the combination.

In a more intricate variation of the above last approach, two annular reflectors are formed about the inner reflector. The thickness of the anti-phase layer is chosen to anti-phase an outer annular metallic reflector to suppress a portion of the tails of the modes, and a rephase layer mesa is formed as above, to provide an index guide that tunes the beam diameters of the modes, so as establish more exactly what portions of the mode tails are suppressed by the outer annular reflector.

There is yet another very important reason why the anti-phase layer should be a semiconductor layer. The last semiconductor layer also serves as the contact layer. The top surface of a contact layer needs to be highly doped, which produces detrimental optical losses if at a peak of the standing wave pattern, but little or no extra losses if at a null. In addition, the semiconductor/dielectric interface can have spurious scattering losses. Meanwhile, in a hybrid mirror, the standing wave pattern invariably has a peak at the bottom interface of the anti-phase layer and at the top interface of the re-phase layer, and both peaks may be amplified because they are in a resonant cavity. On the other hand, the interface between the anti-phase layer and the re-phase layer falls into a null in the standing wave pattern. In the Corzine designs (Fig. 4), these extra losses appear at or near the standing wave peaks, in the window through which the fundamental mode must pass, while in the presently claimed invention, these extra losses are avoided by design, since they are confined to the nulls of the standing wave pattern of the fundamental mode. This fact vastly improves the mode selectivity of the present invention.

Finally, the formation of contoured interfaces, as constructed in Corzine, can produce defects at the surfaces, which also result in spurious optical losses. In the Corzine designs, such spurious optical losses fall into or near standing wave peaks of the fundamental mode, further comprising the mode selectivity. In the present invention, where all the interfaces encountered by the fundamental mode are flat and pristine, such spurious losses are avoided,

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greatly improving the mode selectivity.

In summary, Corzine discloses an optical loss layer that has a similar function (suppression of higher order modes as a function of radius) to that of the anti-phase layer and reflector of the present invention. However, the Corzine structure is very different from the claimed invention as presently defined. Corzine discloses a curved optical loss layer while each of the independent claims as presently on file recites the combination of an anti-phase layer extending across the semiconductor mirror layer and an annular reflector.

CONCLUSIONS:

Accordingly, it is submitted that claims 44-79 define subject matter that is patentably distinguishable over the cited art of record.

Claims 44-79 are thus believed to be in condition for allowance and the application ready for issue.

Corresponding action is respectfully solicited.

PTO is authorized to charge any additional fees incurred as a result of the filing hereof or credit any overpayment to our account #02-0900.

Respectfully submitted,

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APPENDIX A
Version with Markings to show changes made

Cancel Claims 1-43.

Enter the following new claims:

44. A vertical cavity surface emitting laser comprising:

a substrate;

a first mirror formed adjacent to said substrate;

an active region formed adjacent to said first mirror;

a semiconductor mirror formed adjacent to said active region, said semiconductor mirror comprising a plurality of semiconductor mirror layers;

an anti-phase layer formed on said semiconductor mirror;

an annular reflector formed on said anti-phase layer wherein reflections from said reflector are substantially out of phase with reflections from said semiconductor mirror layers to provide mode selective optical loss in order to suppress higher order modes.

45. The vertical cavity surface emitting laser of claim 44 further comprising:

a re-phase layer formed on said anti-phase layer and within said annular reflector.

46. The vertical cavity surface emitting laser of claim 45 wherein a total thickness of said anti-phase layer and said re-phase layer is substantially an integer multiple of ½ wavelength.

47. The vertical cavity surface emitting laser of claim 45 further comprising:

a dielectric mirror formed adjacent to said re-phase layer, said dielectric mirror comprising a plurality of dielectric mirror layers.

48. The vertical cavity surface emitting laser of claim 46 further comprising:

a dielectric mirror formed adjacent to said re-phase layer, said dielectric mirror comprising a plurality of dielectric mirror layers.

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49. The vertical cavity surface emitting laser of claim 44 wherein said anti-phase layer is formed from a semiconductor material.

50. The vertical cavity surface emitting laser of claim 45 wherein said anti-phase layer is formed from a semiconductor material.

51. The vertical cavity surface emitting laser of claim 45 wherein said re-phase layer is formed from a dielectric material.

52. The vertical cavity surface emitting laser of claim 49 wherein said re-phase layer is formed from a dielectric material.

53. The vertical cavity surface emitting laser of claim 44 wherein said annular reflector comprises a conductive metallic material forming an ohmic contact.

54. The vertical cavity surface emitting laser of claim 44 wherein said anti-phase layer is planar.

55. The vertical cavity surface emitting laser of claim 45 wherein said anti-phase layer and said re-phase layer are planar.

56. The vertical cavity surface emitting laser of claim 44 wherein said annular reflector comprises a step function mesa formed in the surface of said anti-phase layer.

57. A vertical cavity surface emitting laser comprising:

a substrate;

a first mirror formed adjacent to said substrate;

an active region formed adjacent to said first mirror;

a semiconductor mirror formed adjacent to said active region, said semiconductor mirror comprising a plurality of semiconductor mirror layers;

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an anti-phase layer formed on said semiconductor mirror;

an annular reflector formed on said anti-phase layer, said annular reflector defining an optical axis of said laser,

said anti-phase layer and said annular reflector cooperating to suppress higher order modes at a predetermined radial distance from said optical axis wherein reflections from said reflector are substantially out of phase with reflections from said semiconductor mirror layers to provide mode selective optical loss at said predetermined radial distance from said optical axis, while also allowing a fundamental mode to propagate along said optical axis.

58. The vertical cavity surface emitting laser of claim 57 further comprising:

a re-phase layer formed on said anti-phase layer and within said annular reflector.

59. The vertical cavity surface emitting laser of claim 58 wherein a total thickness of said anti-phase layer and said re-phase layer is substantially an integer multiple of ½ wavelength.

60. The vertical cavity surface emitting laser of claim 58 further comprising:

a dielectric mirror formed adjacent to said re-phase layer, said dielectric mirror comprising a plurality of dielectric mirror layers.

61. The vertical cavity surface emitting laser of claim 59 further comprising:

a dielectric mirror formed adjacent to said re-phase layer, said dielectric mirror comprising a plurality of dielectric mirror layers.

62. The vertical cavity surface emitting laser of claim 57 wherein said anti-phase layer is formed from a semiconductor material.

63. The vertical cavity surface emitting laser of claim 58 wherein said anti-phase layer is formed from a semiconductor material.

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64. The vertical cavity surface emitting laser of claim 58 wherein said re-phase layer is formed from a dielectric material.

65. The vertical cavity surface emitting laser of claim 62 wherein said re-phase layer is formed from a dielectric material.

66. The vertical cavity surface emitting laser of claim 57 wherein said annular reflector comprises a conductive metallic material forming an ohmic contact.

67. The vertical cavity surface emitting laser of claim 57 wherein said anti-phase layer is planar.

68. The vertical cavity surface emitting laser of claim 58 wherein said anti-phase layer and said re-phase layer are planar.

69. The vertical cavity surface emitting laser of claim 57 wherein said annular reflector comprises a step function mesa formed in the surface of said anti-phase layer.

70. A vertical cavity surface emitting laser comprising:

a substrate;

a first semiconductor mirror formed adjacent to said substrate;

an active region formed adjacent to said first semiconductor mirror;

a second semiconductor mirror formed adjacent to said active region, said second semiconductor mirror comprising a plurality of semiconductor mirror layers;

a planar semiconductor anti-phase layer formed on said semiconductor mirror, said anti-phase layer comprising a semiconductor mirror layer;

an annular ohmic contact formed on said anti-phase layer, said annular ohmic contact defining an optical axis of said laser and providing an annular reflective surface at a predetermined radial distance from said optical axis,

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said anti-phase layer and said annular reflective surface cooperating to suppress higher order modes at a predetermined radial distance from said optical axis wherein reflections from said reflective surface are substantially out of phase with reflections from said semiconductor mirror layers to provide mode selective optical loss at said predetermined radial distance from said optical axis, while also allowing a fundamental mode to propagate along said optical axis;

a planar dielectric re-phase layer formed on said semiconductor anti-phase layer; and

a dielectric mirror formed on said dielectric re-phase layer, said dielectric mirror comprising a plurality of dielectric mirror layers, wherein said dielectric re-phase layer comprises a dielectric mirror layer and further wherein a total thickness of said anti-phase layer and said re-phase layer is substantially an integer multiple of ½ wavelength.

71. A vertical cavity surface emitting laser comprising:

a substrate;

a first mirror formed adjacent to said substrate;

an active region formed adjacent to said first mirror;

a semiconductor mirror formed adjacent to said active region, said semiconductor mirror comprising a plurality of semiconductor mirror layers;

a planar anti-phase layer formed on said semiconductor mirror;

an annular reflector formed on said anti-phase layer, said annular reflector defining an optical axis of said laser,

said anti-phase layer and said annular reflector cooperating to suppress higher order modes at a predetermined radial distance from said optical axis wherein reflections from said reflector are substantially out of phase with reflections from said semiconductor mirror layers to provide mode selective optical loss at said predetermined radial distance from said optical axis, while also allowing a fundamental mode to propagate along said optical axis; and

a planar re-phase layer formed on said anti-phase layer,

wherein a planar thickness of said anti-phase layer and said re-phase layer is spatially varied with a step function at a predetermined radial distance from said optical axis to introduce a lateral index guide.

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72. The vertical cavity surface emitting laser of claim 71 wherein a total thickness of said anti-phase layer and said re-phase layer is substantially an integer multiple of ½ wavelength.

73. The vertical cavity surface emitting laser of claim 71 further comprising:
a dielectric mirror formed adjacent to said re-phase layer, said dielectric mirror comprising a plurality of dielectric mirror layers.

74. The vertical cavity surface emitting laser of claim 72 further comprising:
a dielectric mirror formed adjacent to said re-phase layer, said dielectric mirror comprising a plurality of dielectric mirror layers.

75. The vertical cavity surface emitting laser of claim 71 wherein said anti-phase layer is formed from a semiconductor material.

76. The vertical cavity surface emitting laser of claim 72 wherein said anti-phase layer is formed from a semiconductor material.

77. The vertical cavity surface emitting laser of claim 72 wherein said re-phase layer is formed from a dielectric material.

78. The vertical cavity surface emitting laser of claim 76 wherein said re-phase layer is formed from a dielectric material.

79. The vertical cavity surface emitting laser of claim 71 wherein said annular reflector comprises a conductive metallic material forming an ohmic contact.

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